

Conceptual Change and Computer-Assisted Instruction

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We conducted a study to determine whether a computer-assisted instruction program in neuroanatomy helped first-year medical students to form biomedical concepts, and to correct their misconceptions. Using questionnaires and interviews, we elicited concepts and misconceptions held by the students, in the domain of cranial nerve anatomy. The computer program exposed the students to the information they required to answer the scenario-based questions. Our study found that the students' number and types of misconceptions did not decrease after use of the computer-assisted instruction program. Our findings suggest that designers of computer-assisted instruction programs should determine the common misconceptions that student hold, and should target the programs to correct these misconceptions.

1. EVALUATION OF CAI

In recent years, the medical educational system has been striving to keep abreast of the rapid expansion of medical information and the increasing specialization of medical practice [1]. Computer-assisted instruction (CAI) is seen as an adjunct in the medical curriculum, because it promises self-paced, interactive instruction for medical students. The high cost and high profile of CAI have prompted several researchers to call for improved evaluation of CAI programs in the curriculum [2]. Many scientific fields have identified important concepts that are misunderstood frequently. CAI programs have been tailored to target these concepts [3, 4]. Historically, medicine has concentrated on the transfer and evaluation of factual information, rather than on the cognitive-science aspects of how students represent medical knowledge. However, the importance of basic-science knowledge in improving clinical reasoning has been demonstrated in a number of studies: Although experts do not use basic-science concepts explicitly [5], their organization of concepts is key to effective problem solving [6, 7]. Few data are available on what the common misconceptions in biomedicine are, or on how we can correct them [8]. One of the few theories of conceptual understanding of biomedical knowledge is the work by Feltovich and colleagues on conceptual structures and the formation of misconceptions [9–11]. We found this model useful for assessing how students structured information, and what the implications of these

conceptual structures are for the students' problem-solving abilities.

In this study, we assessed whether use of a specific CAI program formed or changed concepts held by medical students. We selected neuroanatomy — a topic in basic medical science. We used BrainStorm, a CAI program in neuroanatomy developed at Stanford University, and used in the Medical School's first-year neuroanatomy course. We concentrated on the subsection of cranial nerves (CNs) within BrainStorm. To assess whether BrainStorm promoted the formation or change of useful conceptual structures in medical students, we required a method for classifying concepts and misconceptions, as well as a method for eliciting the conceptual structures held by the students.

Balla and colleagues [6] have shown that traditional forms of assessment of basic-science knowledge (e.g., multiple-choice questions and essays) do not reflect conceptual organization. We therefore used a more time-consuming technique — that of the questionnaire accompanied by the student's verbalization of her thinking as she attempted to answer each question.

2. CONCEPTUAL STRUCTURES

Students are introduced incrementally to new, complex material in medical training. During this learning phase, they construct and refine models of the domain, called *conceptual structures*. They form misconceptions when excessive demands are made on their cognitive abilities. We used the subset of Feltovich's classification that was relevant to the neuroanatomy domain:

- *Oversimplification of complex and irregular structure:* Superficial similarities across structures are used as a basis to ignore specific features. For example, all CNs are learned in terms of their nucleus, motor, and sensory components, without regard to specific details of each nerve.
- *Overreliance on a single basis for mental representation:* New concepts are framed in terms of known concepts. For example, because students learn monosynaptic reflexes first, they continue to use that model for all reflexes, instead of the more complex polysynaptic model.
- *Overreliance on top-down processing:* Specific details about a case are not considered as strongly as are general abstractions. For example, when presented with an asthma patient scenario, a student might

ignore disease manifestations specific to the patient and instead concentrate on the general diagnosis of asthma.

- *Context-independent conceptual representation.* Concepts are generalized, making it difficult for a student to recognize contexts in which they may be applicable. For example, knowing that CNs in general may cross the midline to innervate contralateral structures does not allow a student to answer a question about a specific nerve.
- *Overreliance on precompiled knowledge structures.* The student learns “recipes” for what to do when faced with new cases, without considering the logic of the steps.
- *Rigid compartmentalization of knowledge components.* For example, CNs are learned individually as lists, making it difficult for the student to understand the interrelationships of the structures. Components are assumed to work independently.

Textbooks and medical-school courses tend to oversimplify concepts to make the concepts easier for students to learn [11]. Once formed, misconceptions compound one another and require explicit correction through relearning concepts [9]. Recent research in problem-based learning (PBL) demonstrates the importance of forming flexible conceptual structures and of correcting misconceptions early [12]. Misconceptions that are not corrected through feedback lead to increased error rates when students later try to reason about diseases and underlying pathophysiology [12]. If the types of misconceptions in a domain, such as neuroanatomy, have been identified, the way is open for the development of CAI programs that interactively recognize, classify, and correct misconceptions.

3. METHODS

Our sample consisted of seven first-year medical students in the Stanford School of Medicine. All students were asked to answer a questionnaire on neuroanatomy, to use the BrainStorm program, and then to answer a second similar questionnaire. BrainStorm runs on the Apple Macintosh® computer using the SuperCard 1.6 authoring tool from Aldus Software. The program comprises an extensive collection of information on neuroanatomy: over 230 text-information cards, 54 line-diagram cards, 43 digitized color cross-sections (see Figure 1), and 13 gross dissection images. Students use the mouse to click on structures in the cross-sections to obtain information, or to move to different levels. A multiple-choice quiz is provided for students to test themselves on neuroanatomy. There is an interactive CN examination in which students add and remove CN lesions, and then “examine” a patient to see the associated clinical signs.

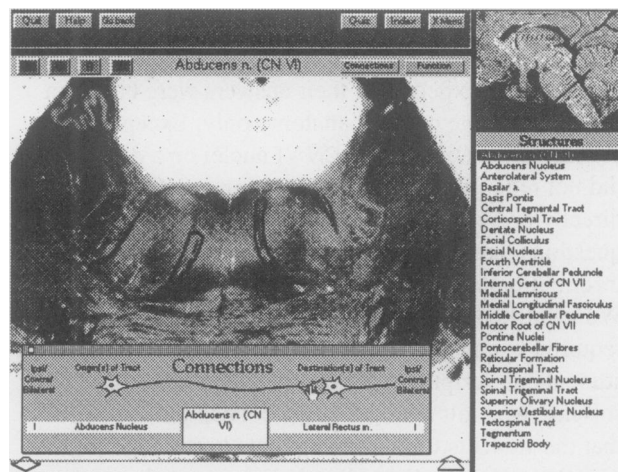


Figure 1. A cross-section image from BrainStorm. Structures are highlighted by selecting their name from a list (right), or locating them on the cross section.

BrainStorm is a highly cross-linked, interactive image and information browser for neuroanatomy.

The questionnaire consisted of five questions — two written answers, and three verbal responses — administered in an interview. Questions focused on the neuroanatomy and function of the CNs — in particular CNs IV, VI, VII and IX. The first two questions tested factual knowledge (see Table 1). The three verbal-response questions were scenario-based and required several steps in problem solving, from identifying the presenting complaint, to deducing its cause and considering other possible lesions or symptoms. During the interview session, we asked the students to think aloud about the problems, without setting a time restriction for their replies. If they were silent for longer than a few seconds, we prompted them to continue to vocalize their thoughts. This method of interview does not affect adversely the analytical process [13]. We tape recorded interviews, and later transcribed and analyzed them.

After the questionnaire, the students were trained to use BrainStorm in a 5- to 10-minute tutorial. All students had some Macintosh experience, so they did not require basic computer training. We asked the students to use BrainStorm for 40 to 80 minutes (the mean was 62 minutes); specifically, they studied those cards on CNs IV, VI, VII and IX about which we would ask in the posttest questionnaire. All students began the BrainStorm session in the interactive CN examination screen, and were free to browse cross-section, diagram, gross dissection, or textual information as they desired. The amount of information they were asked to cover in the allotted time was not unreasonable, as all students had studied the cranial nerves previously, so BrainStorm simply refreshed their knowledge of the subject.

A posttest questionnaire in the same format as the pretest one was then administered. As these students did not have clinical experience, their answers were based on their knowledge of neuroanatomy only. Except for asking the location of the CN VI nuclei on a diagram, we did not request any other information in a form that was directly presented in BrainStorm. Instead, we asked questions that required the students to manipulate the information provided by BrainStorm.

We identified major concepts and facts that the students required to answer the questions (see Table 1). From the students' descriptions of how they approached problem solving, we built a model of the conceptual structures that the students used to manipulate knowledge for that question. We then listed missing factual and conceptual information. Misconceptions were categorized according to Feltovich's classifications (see Table 2).

We compared the number and types of misconceptions demonstrated by students in the pre- and posttest questionnaires. We expected to see a reduction in misconceptions if Brainstorm was effective in modifying students' conceptual structures.

4. RESULTS

Review of tracker files of the students' paths through the BrainStorm program revealed that all students covered over 80 percent of the requested sections and information cards, so they were exposed to that percentage of the information required in the posttest questionnaire. In Table 2, the number in parentheses is the number of

students demonstrating the misconceptions listed. Some students displayed multiple misconceptions in their answers to a single question. All students made some errors in answering the questions. Table 2 demonstrates that some misconceptions were particularly pervasive among students in our group. In pretest question 3, six of seven students oversimplified the corneal reflex to a monosynaptic representation. The variety of misconceptions was larger in answers to other questions. As an example of the classification process we shall present one student case in detail. In the pretest questionnaire, the student answered the first two written questions accurately. When asked about the corneal reflex, the student volunteered that there were mono- and polysynaptic reflexes, but did not consider which type of reflex the corneal reflex was. Although the student stated correctly the sensory and motor components, he simplified the reflex into a monosynaptic representation. The student itemized the functions of CN VI, and used this mode of representation to identify CN VI correctly as being affected by the tumor. He realized that CN VII is near CN VI, because of the numbering system, and verbalized a list of functions of the seventh nerve. He did not think of the two nerves in terms of their spatial relationship. He therefore overlooked that the genu of CN VII is near the nucleus of CN VI. This error is a good example of compartmentalization — the student studied each nerve separately, which made it difficult for him to apply his new knowledge to this problem, which required considering multiple CNs together.

Questions	Concepts and facts reflected in answers
Pretest	
1. Mark the location of the CN IV nuclei on a diagram.	Concept: The spatial orientation of nuclei.
2. Which nerve(s) control secretion of the parotid gland?	Concept: Association of proximity with function. Facts: Facial nerve (CN VII) is intimately related to the parotid, but secretion is controlled by CN IX.
3. Describe the corneal reflex.	Concepts: Reflexes may be monosynaptic or polysynaptic. Facts: There are specific muscles of innervation and medial longitudinal fasciculus.
4. A cerebellar tumor in the fourth ventricle is compressing the pons causing double vision and lateral rectus palsy. What other nerve lesions may be present?	Concepts: One lesion may affect multiple nerves depending on spatial relationships. Facts: CN VII loops around the nucleus of CN IV (genu of Facial nerve) and protrudes into the fourth ventricle.
5. A patient presents with left superior oblique and right-sided lateral rectus palsies. Describe possible lesion(s) to account for this case.	Concepts: Try to explain findings with one lesion. CNS may provide contralateral innervation. Facts: Trochlear nerve decussates and supplies contralateral side.
Posttest	
1. Mark the location of CN VI on a diagram.	Concept: The spatial orientation of nuclei.
2. What is the nerve supply of digastric muscle?	Concept: Some muscles have dual nerve supply. Fact: There are two nerves that innervate the digastric muscle.
3. Describe the gag reflex.	Concepts: Reflexes may be monosynaptic or polysynaptic. Sensory innervation has unclear demarcation.
4. What is the location of cavernous sinus? Which nerves will be involved in an infection of cavernous sinus? How does infection spread to cavernous sinus?	Concepts: The spatial location of a structure. Nerves and branches travel through the cavernous sinus. Cavernous sinus is a venous structure. Infection may spread via the blood.
5. A patient cannot shrug her right shoulder. What clinical examination would you do?	Concepts: Other nerves may be involved because of spatial location (CNS IX, X, XII). Facts: Test the sternocleidomastoid as CN XI is involved. Exclude CN involvement by testing function.

Table 1. Questions, and the concepts and facts that they are designed to elicit.

The student understood the concept that some nerves may cross the midline, leading to a combination of ipsi- and contralateral symptoms, but he did not understand that CN VI does not cross the midline. We classified this misconception as context-independent conceptual representation. In the posttest questions, the student correctly located the CN VI nuclei on a diagram and knew the innervations of the digastric muscle. He also described accurately the location of the cavernous sinus and the nerves that pass through that sinus. The last question caused problems for the student because it required that he think about the spatial relations among nerves and among nuclei.

Our testing did not reveal any changes, after use of BrainStorm, in students' problem-solving approach, conceptual organization, or the number and types of misconceptions, although the students had covered 80 percent of the factual material asked about in the posttest questionnaires.

5. DISCUSSION

The interviews made it clear that the students took one of two approaches to remembering the cranial nerves. Six out of the seven students used a list-based approach, demonstrated by the way they retrieved information before considering the specific problem. The success of this approach depended on the amount of detail that the student had incorporated in her model. For example, one student had a strong sense of exceptions to normal. She tagged nerves with labels — recalling the Trochlear nerve as “the bizarre one” because it supplied the contralateral side. All students who used list-based

memory schemes had difficulty reasoning about problems that required that they use information in a manner different from the way they had acquired it. Only one of the students had a three-dimensional view of the anatomy. Although this student lacked specific details in some areas, her model was more flexible when she reasoned about problems. This representation of neuroanatomy resulted in her making fewer over-simplifications and reductionist errors.

The students' approaches to learning and using new information did not change with use of the program, which suggests that students incorporate new information from BrainStorm into their current — possibly erroneous — conceptual structures. BrainStorm, like almost all CAI programs, is designed to present information in an interesting, interactive fashion. It is not designed to detect or correct students' misconceptions.

Medicine has traditionally concentrated on teaching facts rather than concepts. Only recently has there been interest among educators in reaching consensus on the important and difficult concepts that should be emphasized in the medical curriculum [14].

Identification of common misconceptions held by students when they are learning these important concepts will allow educators and CAI creators to design ways to promote cognitive flexibility in students. Feltovich and colleagues demonstrated that different types of misconceptions required different corrective approaches [9]. We found interviews to be an effective way of eliciting student's conceptual structures, although they were time consuming. Mapping the student's path through a CAI program, as has been done by Stevens and colleagues

Responses	Misconceptions
Pretest 1. Location not marked correctly (3) 2. Incorrect (2), CN VII nerve suggested 3. Did not consider polysynaptic reflex (6) 4. Did not identify CN VI as cause for symptoms (2). Did not know the interrelationship of CN VI and CN VII, but considered nerves individually (3) 5. Did not know CN IV supplies contralateral side (4) Knew that a CN may decussate but did not know which (2) Ignored laterality of symptoms presented in the question and only considered nerves (1)	Factual information lacking. Factual information lacking. Oversimplification of structure. Proximity of CN VII to the parotid gland implies association. Overreliance on a single basis for mental representation. Factual information lacking Compartmentalization; each CN learned separately. Overreliance on a single basis for representation. Context independent conceptual representation. Overreliance on top-down processing. Specific features of a case are overlooked.
Posttest 1. Location not marked correctly (4) 2. Did not know that the digastric has dual nerve innervation (4) Knew dual innervation of digastric, knew only one nerve (2) 3. Did not know about mixed innervation; attempted to explain in terms of one input and one output (5) 4. Could not describe location of cavernous sinus, knew approximate location (4) Did not know which nerves pass through or gave partially incorrect answers (4) Knew the cavernous sinus is a venous structure, but did not consider blood borne disease as passage of infection (3) 5. Did not consider examining for other nerve involvement (4)	Factual information lacking. Overreliance on a single basis for mental representation. Factual information lacking. Oversimplification of complex and irregular structure. Overreliance on precompiled knowledge structures. Compartmentalization, each CN learned separately. Difficulty combining knowledge. Overreliance on top-down processing. Specific features of a case are overlooked. Compartmentalization; each CN learned separately.

Table 2. The number and type of student responses classified as misconceptions. The number in parentheses is the number of students who demonstrated the misconception.

[15, 16], although successful in detecting student's knowledge problems during diagnostic problem solving, may not be useful in inferring misconceptions.

6. CONCLUSIONS

Our study has shown that exposing students to neuroanatomy information in the Brainstorm CAI browsing environment does not change their problem-solving approach, or conceptual organization, presumably because the students incorporate new information using their current conceptual structures. We believe that Feltovich's model of conceptual structures and misconceptions is a useful tool for classifying misconceptions. The results of the study (see Table 2) show that incorrect answers by a student may be due to a variety of different misconceptions. Because errors may be due to a variety of possible misconceptions, CAI program designers should not assume a single model of the user, but rather should configure explanation dynamically for the user once the program recognizes the types of misconceptions that the user has.

Our findings suggest that designers of CAI programs should determine the common misconceptions that students hold, and should target the programs to correct these misconceptions, with the goal of improving reasoning ability.

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